Methods for Modeling Realistic Playing in Plucked-String Synthesis: Analysis, Control and Synthesis

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1. Introduction
2. Structure of the Synthesizer
3. Analysis of Recorded Tones & Resynthesis
   - Dynamics and pizzicato
4. Control
5. Synthesis Using PWSynth
6. Conclusions and Future Plans

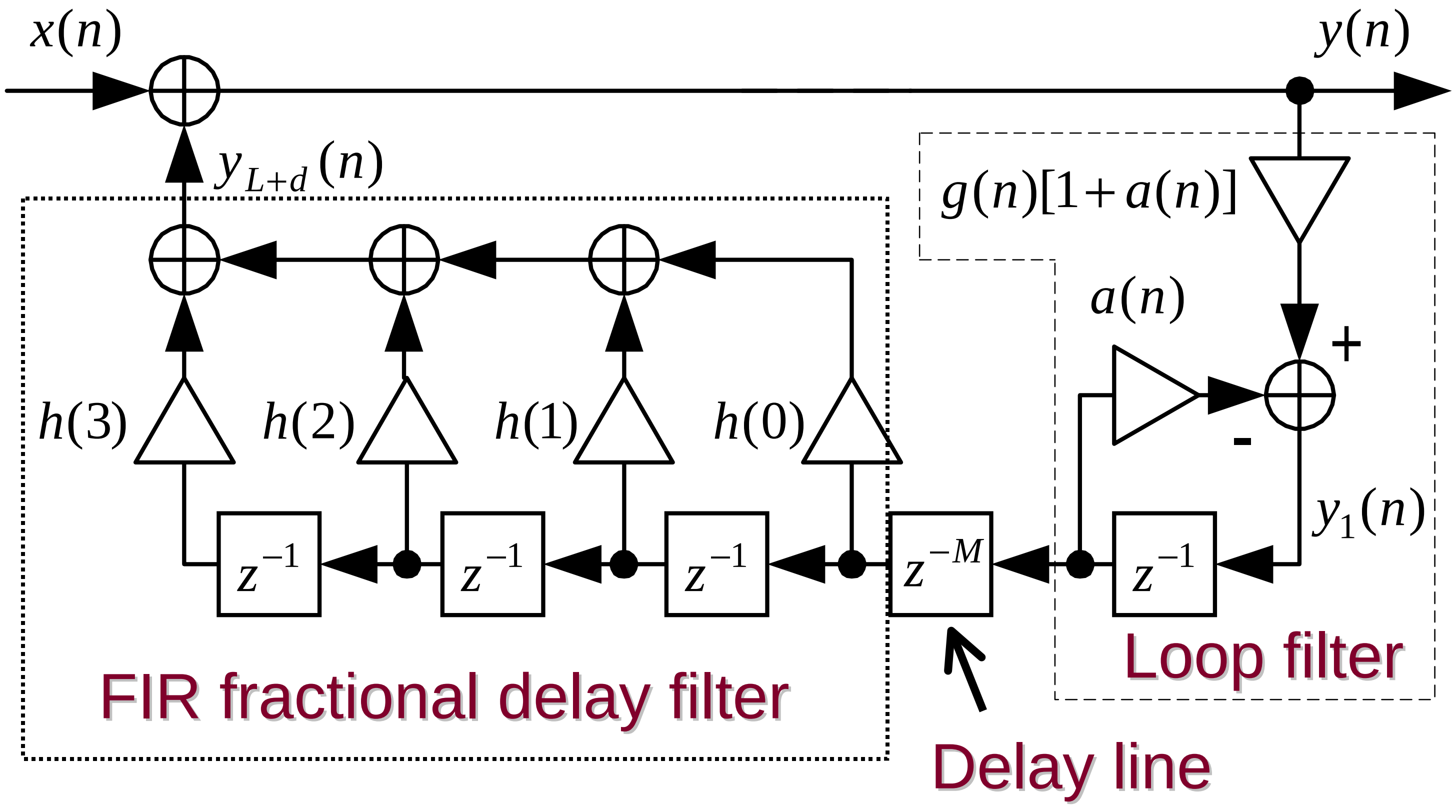
1. Introduction

- Physical modeling has been an active research field for the past decade
- Most popular approach based on digital waveguides
  - Commuted Waveguide Synthesis (Smith, 1993; Karjalainen *et al.*, 1993)
- Our current guitar synthesizer
  - Implemented using PWSynth and ENP
  - Based on analysis of recorded guitar tones
  - Sound example: Prelude by J. S. Bach

2. Structure of the Synthesizer

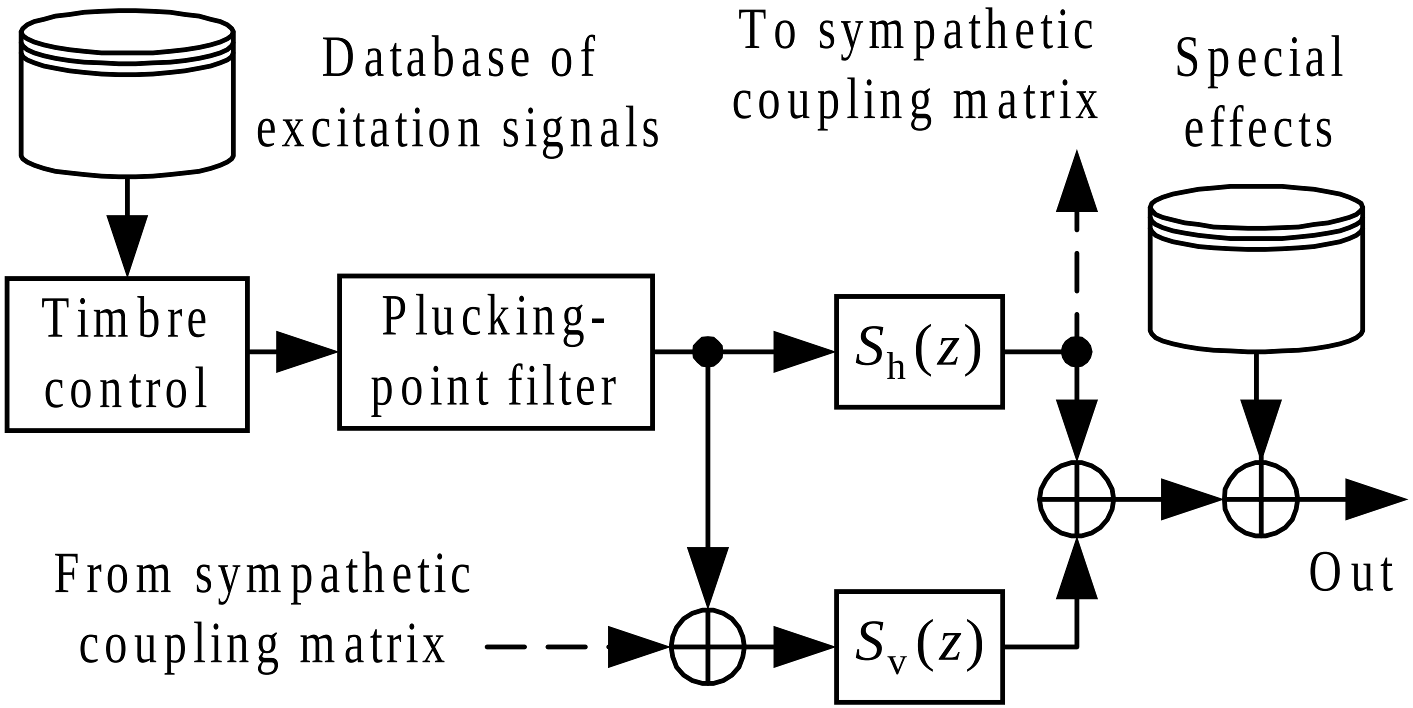
- Basic string model

  (Jaffe & Smith, 1983; Välimäki *et al.* 1996)



2. Structure of the Synthesizer (2)

- Commuted waveguide synthesis (sampling + modeling)
- Excitations & special effects stored in a database



3. Analysis of Recorded Tones

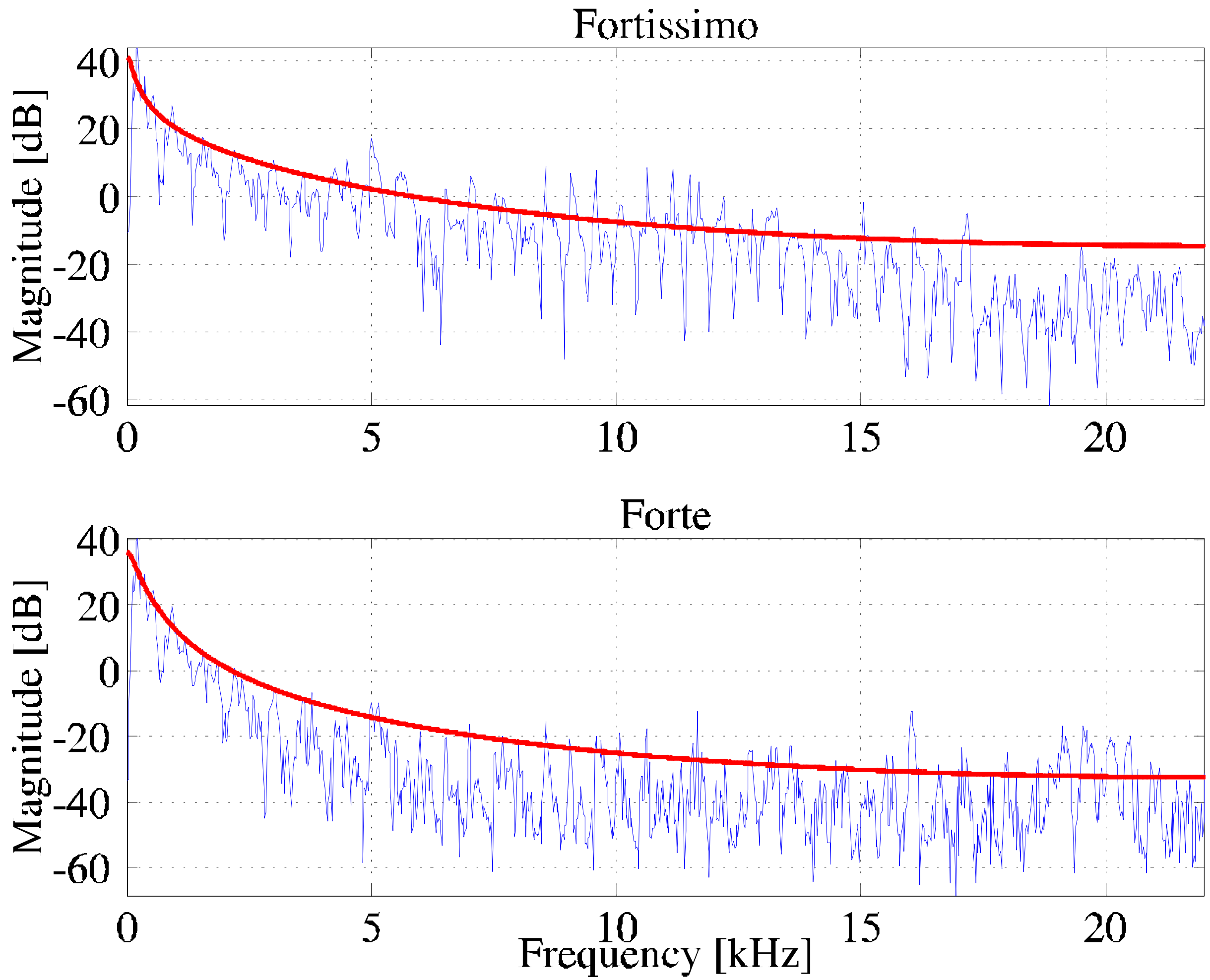
- Anechoic recordings of guitar playing
- Signal analysis using short-time Fourier transform (Välimäki *et al.* 1996)
- Parameter estimation using iterative methods (Erkut *et al*., AES Conv., Feb. 2000)
- Excitation signals obtained by subtracting the harmonics from recorded tones, and equalization (Tolonen 1998; Välimäki & Tolonen, JAES 1998)

3. Modeling Dynamics

- Use the Timbre filter to model dynamics
  - 2nd-order IIR filter instead of a one-pole filter
  - Change coefficients according to dynamic level
- Store filter parameters instead of excitation signals (i.e., save memory)
- Enables interpolation of dynamic levels between the analyzed cases (forte, piano, pianissimo etc.)
- Changing dynamics by scaling & lowpass/highpass filtering the excitation signal (Erkut *et al*. 2000)

3. Modeling Dynamics (2)

- Differences in the spectra at various dynamic levels
  – Overall level
  – Spectral tilt
- **Spectral envelope fit using LPC (red line)**

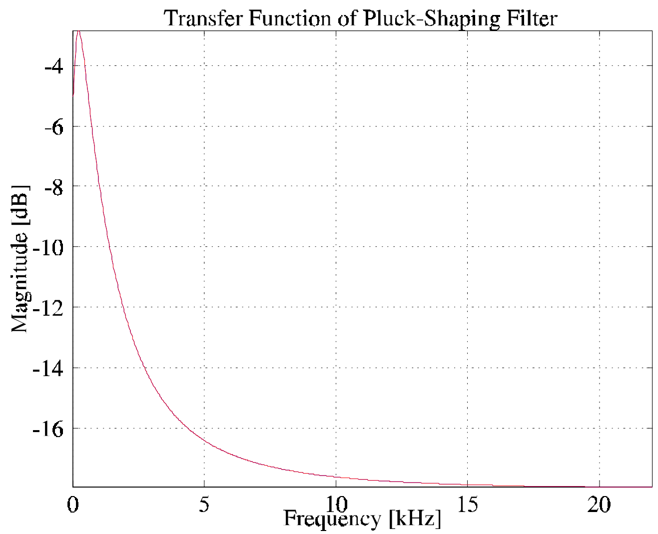


3. Modeling Dynamics (3)

- Divide the 2nd-order transfer functions

$$A(z) = \frac{g_a}{1 + a_1 z^{-1} + a_2 z^{-2}} \quad \text{and} \quad B(z) = \frac{g_b}{1 + b_1 z^{-1} + b_2 z^{-2}}$$

$$\rightarrow H(z) = \frac{A(z)}{B(z)} = \frac{(g_a / g_b)(1 + b_1 z^{-1} + b_2 z^{-2})}{1 + a_1 z^{-1} + a_2 z^{-2}}$$



- Filter *H*(*z*) is used as the Timbre filter

Sound Examples: Dynamic Levels

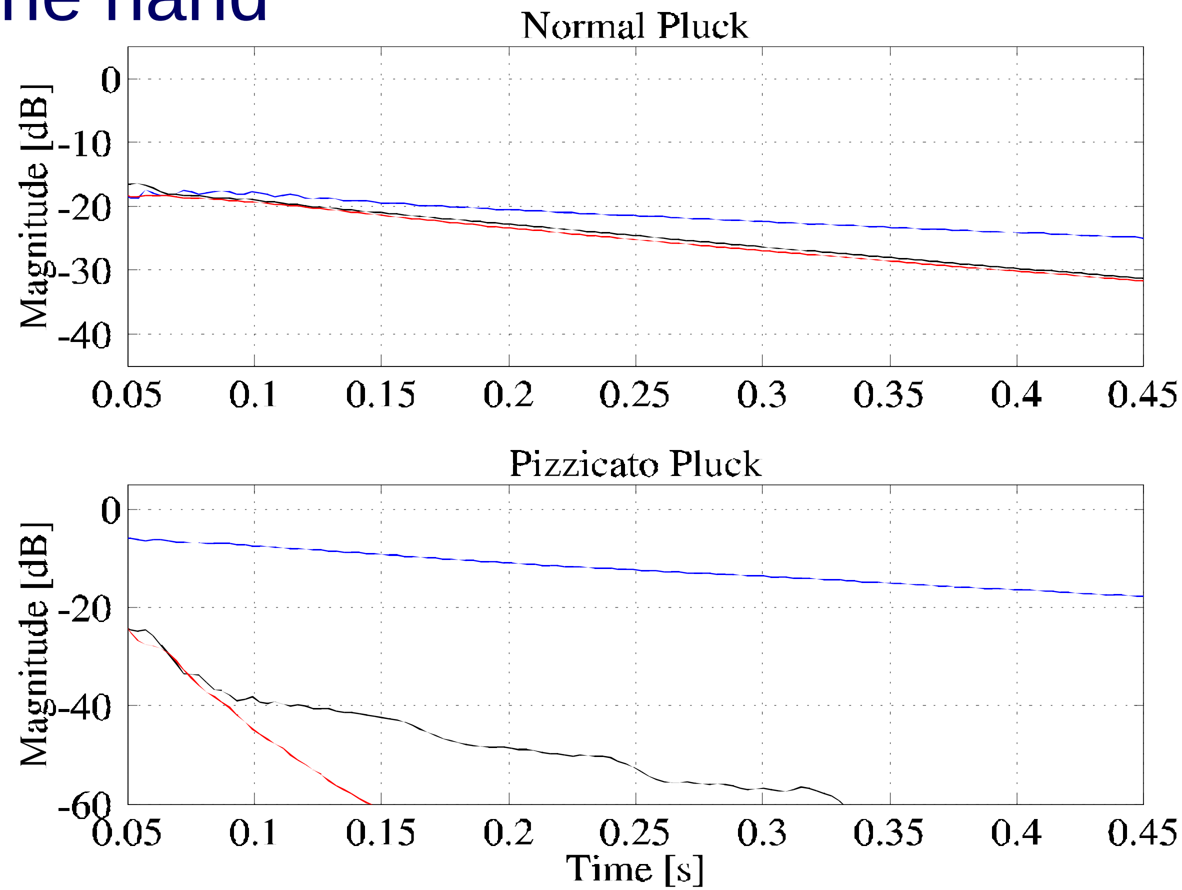
- Now we can synthesize different dynamic levels using one excitation signal but different Timbre filter
- Comparison of synthetic tones

1. **Fortissimo** (without Timbre filter)
2. **Forte** (without Timbre filter)
3. **Forte** (with fortissimo excitation & Timbre filter)

Playlist = { 1 2 3 pause 1 2 3 pause 2 3 }

3. Pizzicato Tones

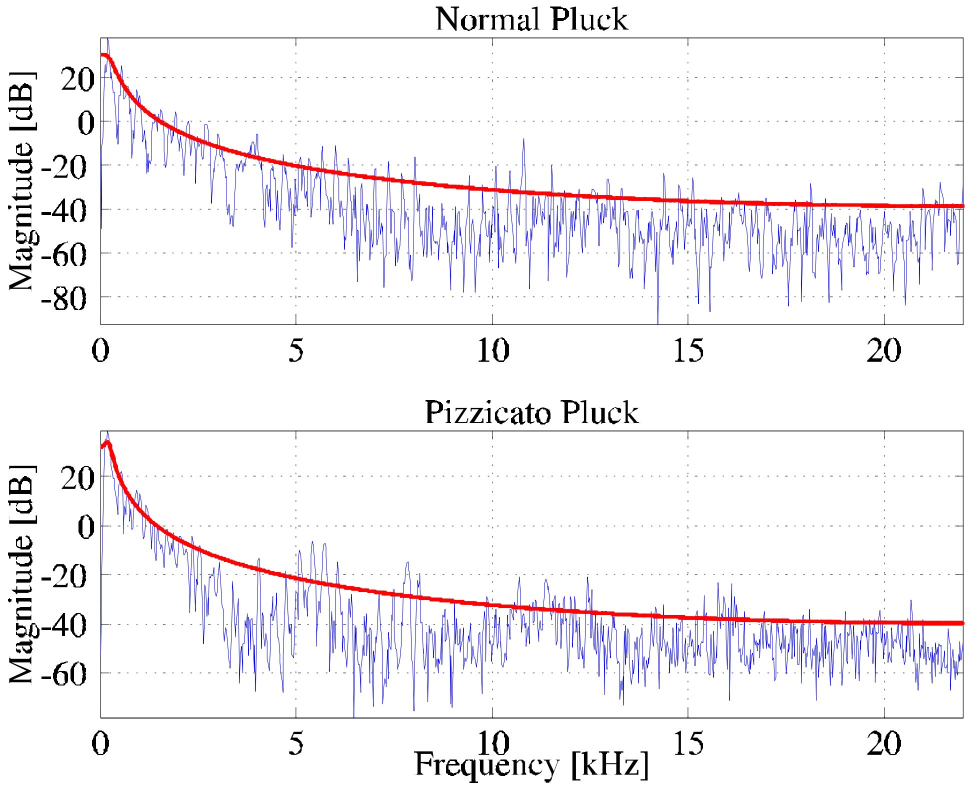
- Pizzicato = pluck the string & lightly damp the string with the palm of the hand



- Pizzicato tones decay fast !

3. Pizzicato Tones (2)

- How to synthesize pizzicato tones efficiently
  - – Change the Loop filter & Timbre filter



- Timbre filter obtained just like above

  (2nd-order LPC fit and divide transfer functions)

Laurson, Erkut & Välimäki 2000

Pizzicato Sound Examples

- Comparison of synthetic tones

1. **Normal pluck** (without Timbre filter)
2. **Pizzicato** (without Timbre filter)
3. **Pizzicato** (Normal pluck excitation & Timbre filter)

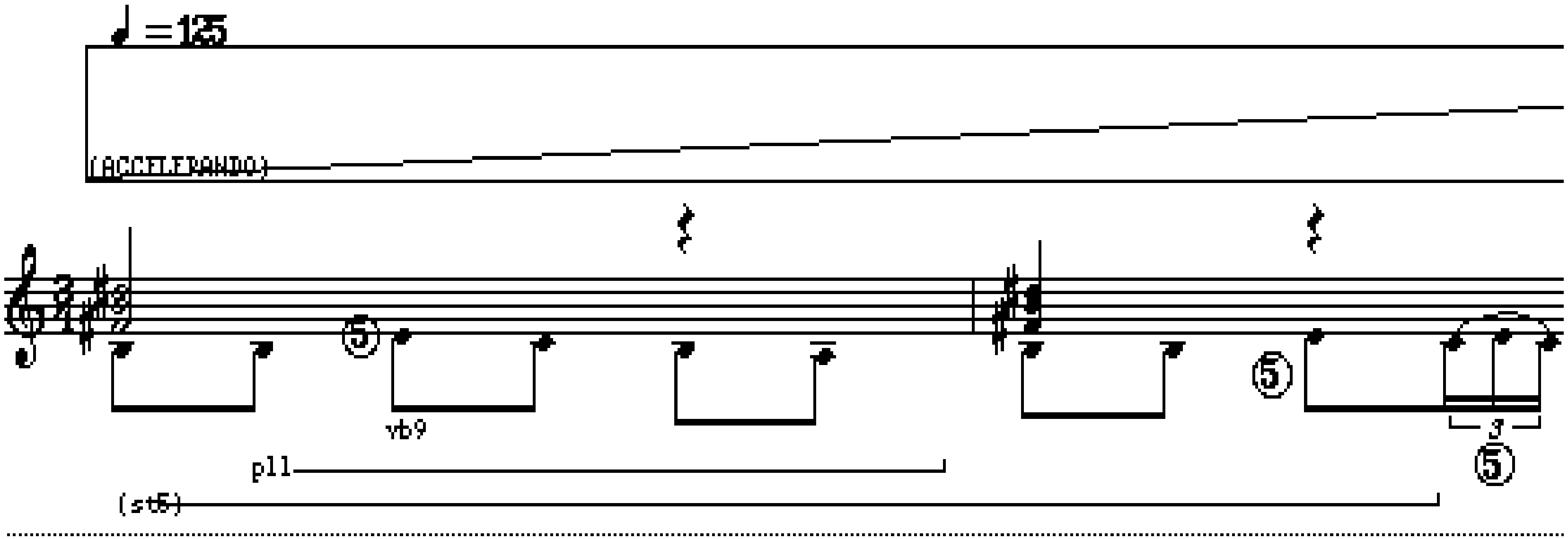
Playlist = { 1 2 3 pause 1 2 3 pause 2 3 }

4. Control

- Control with the help of ENP (Expressive Notation Package)
  - Lisp-based package in PatchWork
  - Supports standard & non-standard expressions (Laurson *et al.*, ICMC'99; Kuuskankare & Laurson, JIM'2000)
- User can define a score & add expression info

4. Control (2)

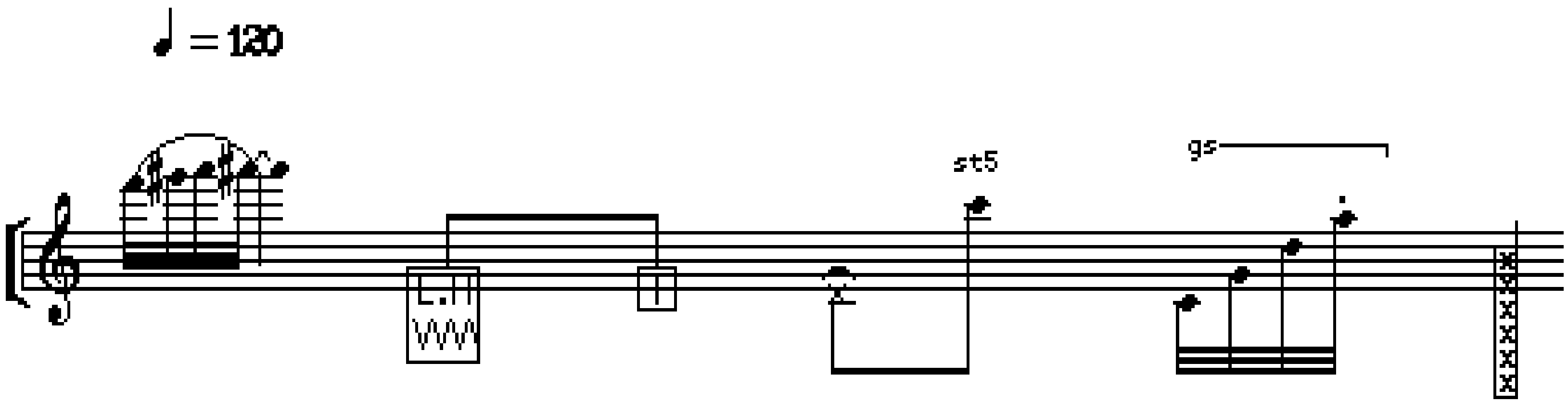
- Example from the classical guitar repertoire



- Sound example: *Madroños* by F. M. Torroba

4. Control (3)

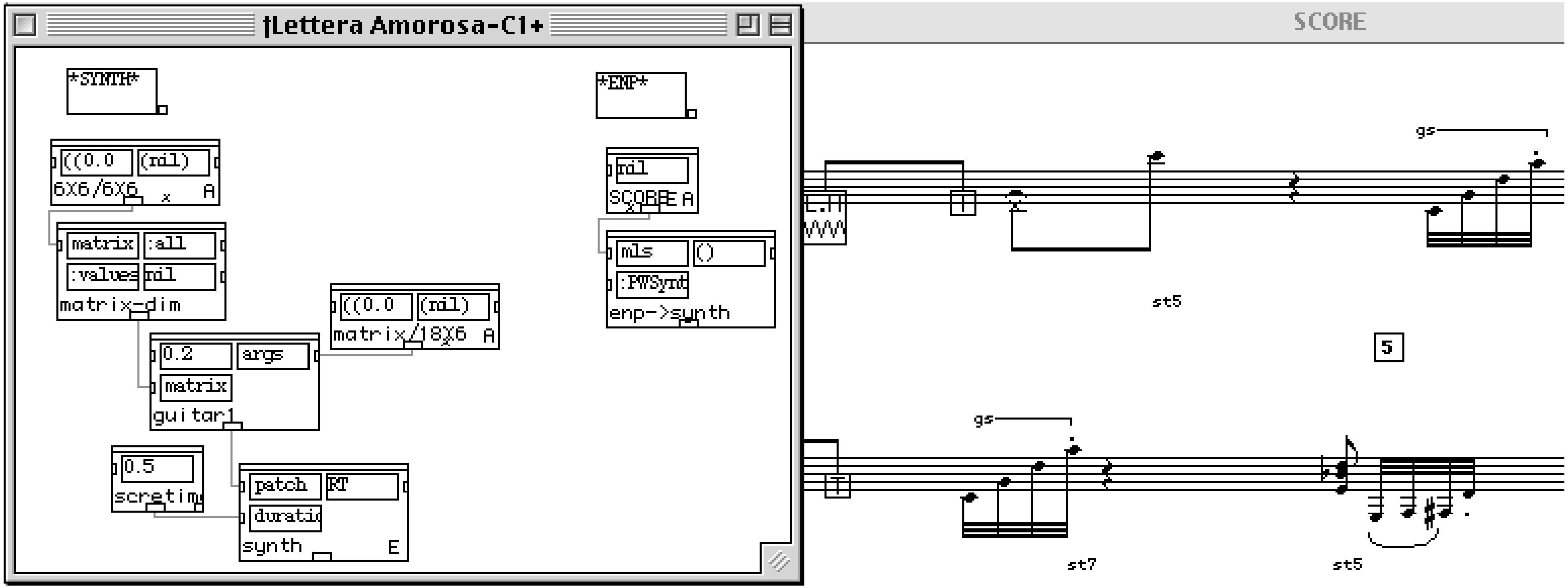
- Example of non-standard, modern notational conventions: special noteheads trigger samples



- Sound example: *Lettera Amorosa* by J. A. Muro
  - Includes special effects, such as sampled knocks & rubbing of strings

5. Synthesis Using PWSynth

- Graphical programming environment for sound synthesis within PatchWork



5. Synthesis Using PWSynth (2)

- Parameters stored in matrices (see below)
- Every parameter has a pathname, such as

  `guitar1/2/lfcoef`

  which points to the loop filter coefficient of the 2nd string of Guitar #1

  – Like in OSC (Wright & Freed, 1997)

matrix/18X6

	SIno	sndno	freq	plgain	lfgain	lfcoef	plpos	freqcor	detune	plposq	plfgain	plfcoef	SIno1	sndno1	gain1	SIno2	sndo2	gain2
1	0.000	0.000	330.6	1.000	0.995	-0.11	0.200	1.000	1.000	0.100	1.000	-0.50	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	1.000	246.9	1.000	0.997	-0.32	0.200	1.000	1.000	0.100	1.000	-0.50	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	2.000	195.9	1.000	0.989	-0.21	0.200	1.000	1.000	0.100	1.000	-0.50	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	3.000	164.8	1.000	0.998	-0.29	0.200	1.000	1.000	0.100	1.000	-0.50	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	4.000	110.0	1.000	0.989	-0.26	0.200	1.000	1.000	0.100	1.000	-0.50	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	5.000	82.40	1.000	0.989	-0.26	0.200	1.000	1.000	0.100	1.000	-0.50	0.000	0.000	0.000	0.000	0.000	0.000

6. Conclusions

- Newest developments in model-based guitar synthesis
- Commuted waveguide synthesis combines modeling & sampling
  - Strings modeled with digital waveguides
  - Excitations & effects extracted from recordings
- Methods were proposed for synthesizing various dynamic levels and pizzicato tones
- Sound examples available at our Web site: http://www.acoustics.hut.fi/demo/dafx2000-synth/

6. Future Research

- Reduce redundancy between excitation signals
  - Model low-frequency body modes with digital resonators, as suggested earlier

    (Välimäki *et al.,* 1996; Tolonen, 1998)
- Reduce the size of the excitation database
- Improved parametrization of excitation signals